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RESPONSES OF DESERT BIGHORN SHEEP TO INCREASED HUMAN RECREATION

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Abstract: Human recreation has been implicated in the decline of several populations of desert bighorn sheep *(Ovis canadensis nelsoni)*. Managers are concerned about the impact of increased recreation on desert bighorn sheep in Canyonlands National Park (NP), Utah, USA, where visitation increased 325% from 1979 to 1994. We compared behavioral responses of sheep to recreational activity between a low visitor use area and a high visitor use area during 1993 and 1994 by observing behavioral responses, distances moved, and duration of responses to vehicles, mountain bikers, and humans on foot. Hikers caused the most severe responses in desert bighorn sheep (animals fled in 61% of encounters), followed by vehicles (17% fled) and mountain bikers (6% fled), apparently because hikers were more likely to be in unpredictable locations and often directly approached sheep. We observed considerable individual heterogeneity in responses of bighorn sheep to the greater human use: some animals lived close to the road corridor and were apparently habituated to the human activities, but other animals avoided the road corridor. In the high-use area, we observed 3 radiocollared sheep that lived closer to the road than expected and found evidence of fewer responses to vehicles by females in spring, less response time of all sheep to vehicles in spring, and fewer responses to mountain bikers compared to the low-use area. Overall, there was an avoidance of the road corridor by most other bighorn sheep in the high-use area where all animals, on average, were found 39% farther from roads (490 ± 19 m vs. 354 ± 36 m) than in the low-use area. This avoidance of the road corridor by some animals represented 15% less use of potential suitable habitat in the high-use area over the low-use area. Increased sensitivity to hikers in the high-use area was suggested by a greater responsiveness by males in autumn and greater distance fled by females in spring. Responses of bighorn sheep were greater when human activity approached at the same elevation, when sheep were moving or standing, when female interactions occurred in spring and summer and male interactions occurred in autumn, and when sheep were farther from escape terrain. We recommend managers confine hikers to designated trails during spring lambing and the autumn rut in desert bighorn sheep habitat.

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Key words: desert bighorn sheep, national parks, *Ovis canadensis nelsoni*, recreation activity.

The deserts of the southwestern United States have experienced large increases in human development and activity in recent years (Bogan et al. 1998). The warm, dry climate encourages people to build vacation homes and to hike, mountain bike, rock climb, raft, and operate off-road vehicles through the sensitive desert ecosystems. Many communities in the region have expanded, including Moab, Utah, where the number of year-round residents has increased. Recreation on public lands has similarly increased; 439,921 people visited nearby Canyonlands NP, Utah, in 1994, an increase of 325% (average = 22% increase/yr) from 1979. Public land managers need to know what effects this rapidly increasing human habitation and visitation are having on wildlife.

One species that may be adversely impacted by the increase in human activity in Canyonlands NP is the desert bighorn sheep. This desert subspecies has declined due to anthropogenic changes including habitat loss, overgrazing by livestock, diseases contracted from domestic livestock, overhunting during the mining era, and loss of water sources (Beuchner 1960; Bailey 1980, 1984; Graham 1980; McCutcheon 1981; Geist 1985). However, there is a scarcity of quantitative data on the impact of human activity on desert bighorn sheep (Krausman et al. 1999).

Several lines of thought exist concerning the effects of recreational activity on bighorn sheep. First, human presence in bighorn sheep habitat may cause sheep to vacate suitable habitat. The loss of usable habitat is significant enough to reduce the population's carrying capacity (K) or rate of growth (r) (Light and Weaver 1973). Recreation may have caused bighorn sheep to abandon habitat in the Pusch Ridge Wilderness,

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Arizona (Etchberger et al. 1989), the San Gabriel Mountains, California (Graham 1971), and some canyons in southeastern Utah (King 1985). Increasing human recreation is 1 of the primary factors that prompted the listing of the California peninsular population of desert bighorn sheep (*O. c. cremnobates*) as an endangered population (U.S. Fish and Wildlife Service 1999). Bighorn sheep have altered their use of water sources when disturbed (Campbell and Remington 1979, Leslie and Douglas 1980). Frequent vehicle activity caused sheep to reduce or abandon their use of water sources and surrounding areas (Jorgensen 1974). Second, energetic losses due to disturbances (flight, loss of foraging time, increase in cortisol and stress levels) might result in deleterious effects on physiology, behavior, or fat reserves of sufficient magnitude to reduce survival and reproductive success of the individual (MacArthur et al. 1979, 1982; DeForge 1981; Stemp 1983; Miller and Smith 1985; Belden et al. 1990). Finally, bighorn sheep may habituate to predictable human activity (Geist 1975, Wehausen et al. 1977, Kovach 1979), including highway traffic (Horesji 1976), hiking (Hicks and Elder 1979, Hamilton et al. 1982, Holl and Bleich 1987), and

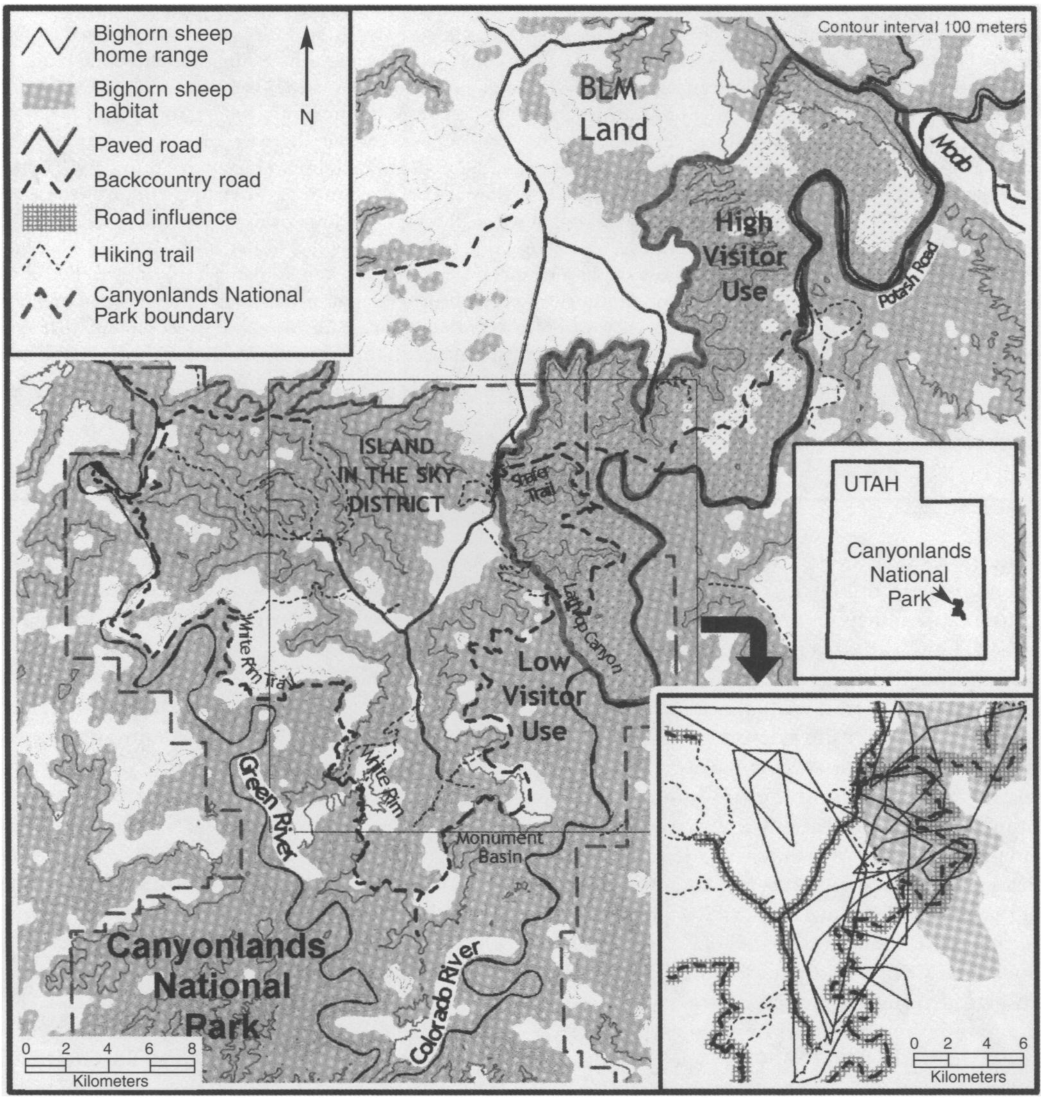

Fig. 1. The Island in the Sky district of Canyonlands National Park, Utah, and vicinity. Polygons in the inset map represent bighorn sheep home ranges.

aircraft (Krausman et al. 1998), or use areas away from disturbance (Wilson et al. 1980).

We investigated the population of desert bighorn sheep located in and near Canyonlands NP, Utah, and observed bighorn sheep–human interactions for evidence of habituation to human recreational activity or, alternately, the avoidance of human use areas. We also used locations of radiocollared animals to test 4 predictions that bighorn sheep were avoiding human activity: (1) home range sizes might be altered by human activity; (2) animals with home ranges that include the low- and high-use areas might spend more time in the low-use portion of their range; (3) animals whose home ranges are bisected by roads might avoid the road; and (4) animals captured and radiocollared in the high-use area might disperse to and use the low-use area at a higher rate than animals captured in the low-use area will disperse to the high-use area.

STUDY AREA

Canyonlands NP, on the Colorado Plateau in southeastern Utah, includes 834,137 ha of cliffs, benches, and canyons. The Colorado and Green rivers divide the park into 3 distinct geographical districts: Island in the Sky, Needles, and Maze. Our study was conducted in the Island in the Sky district, where elevations range from 1,100 to 2,100 m. Cliffs, talus slopes, sheer walls, and wide benches separate the high plateau (i.e., "The Island") from the Colorado and Green river canyons below (Baars and Molenaar 1971). Pinyon pine (*Pinus* spp.) and juniper (*Juniperus* spp.) communities dominate the high plateau, while grasslands, saltbush (*Atriplex* spp.), and blackbrush (*Coleogyne ramosissima*) communities cover the slopes and benches below (Bates and Workman 1983). The climate is classified as cool desert with July temperatures averaging 32.8 °C and January temperatures averaging 2.3 °C.

In 1969, 30–60 desert bighorn sheep inhabited the park (Wylie and Bates 1979). Following designation of the park in 1964 and the cessation of mining in 1964 and cattle grazing in 1975, the bighorn sheep herd in Canyonlands NP increased in size during the 1970s and 1980s (Dean et al. 1977). In 1996, the estimated population of desert bighorn sheep within Island in the Sky and the contiguous Bureau of Land Management (BLM) lands was 250.

The Island in the Sky District (Fig. 1) has received an increase in visitation. Most visitor activity is concentrated along roads, though there has also been an increase in hikers exploring the canyons above and below the White Rim. For example, climbers now frequently scale the pinnacles of Monument Basin in bighorn sheep habitat. Day hiking has increased in the more accessible parts of the Island, and mountain bikers frequently use the 161-km White Rim trail, a 4-wheel-drive road. Caravans of mountain bikers accompanied by support vehicles are common. Day use along the Shafer and White Rim trails exceeded 17,500 vehicles during the study period, 1993–1994 (Fig. 2). This use was concentrated from March to October, with peak use of 134 vehicles/day in May. Overnight backcountry, day hiker, and mountain biker use peaked in the spring and autumn since summer daytime temperatures can be uncomfortable (Jul mean maximum 32.81 °C).

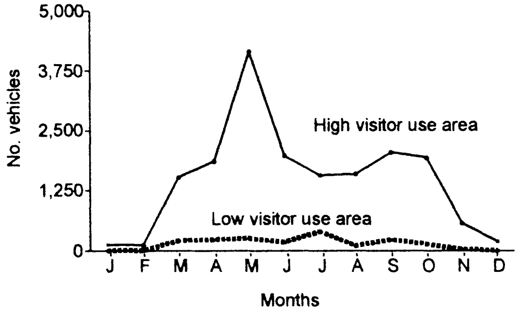

Fig. 2. Number of vehicles driven by park visitors on backcountry roads in Canyonlands National Park, Utah, 1993–1994.

We divided the study population into 2 study areas: low use and high use (Fig. 1). The low-use area was located along the White Rim road south of Lathrop Canyon and included the area west of the Island in the Sky mesa. Approximately 1 vehicle passed along roads/hour during peak visitor months in the low-use area. The high-use area was located at the top of the plateau, along the Shafer trail and White Rim trail as far south as Lathrop canyon, and along the Potash road about 8 km into the BLM land east of the park boundary. Between 5 and 13 vehicles passed along roads/hour during peak visitor months in the high-use area.

METHODS

We observed human–bighorn sheep interactions using 42 radiocollared sheep and observations of noncollared sheep encountered within 3 km of the roads using a combination of radiotelemetry, binoculars, and (10–60×) spotting scopes. Noncollared animals and groups were treated in the same manner as radiocollared animals.

Observations of vehicle and mountain biker interactions between park visitors and bighorn sheep were made while the observer was undetected (mostly) or, in those cases where the visitor(s) might have seen the parked vehicle and maybe (unlikely) the observer, the distances were great enough that we think the visitors were unlikely to alter their behaviors due to our presence. However, opportunistic sightings of visitors hiking were rare, and consequently field assistants initiated 98% of the hiker–bighorn interactions, usually in off-trail situations. Researcher-initiated disturbance trials constituted 24% of all trials in the high-use area and 77% in the low-use area.

When we located a group (≥1 animal) of desert bighorn sheep, we recorded the study area (low use, high use), season (spring [Mar, Apr, May], summer [Jun, Jul, Aug], autumn [Sep, Oct, Nov]), activity (feeding–watering, moving, bedded, standing), group size, and the age-sex composition of the group. When a potential interaction was observed, we recorded the type of human activity, elevation of the disturbance relative to the sheep (i.e., above, level, below), the sheep's distance to the road, and their distance to escape terrain (defined as slopes from 27° to 85°; Smith et al. 1991). Field crews also recorded the distance from the disturbance at which the sheep first alerted (if they alerted), response behavior (see below), distance fled, and duration of response. When field researchers conducted hiker disturbances, they meandered toward the sheep until the researchers were noticed or until they approached as close as 150 m. Behavioral responses were classified based on how most of the group responded; when 2 or 3 sheep were observed, the most severe response was recorded. We used the same general animal response categories used by Stanger et al. (1986); (1) No reaction: bighorns maintained behavior, exhibited no overt sign of response to disturbance. (2) Alert: bighorns terminated their behavior, noted presence of disturbance, exhibited alert behavior. (3) Walked away: bighorns terminated their behavior, immediately walked away from disturbance or exhibited alert behavior and then walked away. (4) Ran away: bighorns terminated their behavior, immediately ran away from disturbance or exhibited alert behavior and then ran away. For ease of discussion, these 4 response categories were further grouped as: nonflight: no reaction or alert; flight: walked away or ran away.

Using univariate logistic regression, we analyzed the influence of each independent variable (i.e., study area, season, activity, group size, group composition, relative position of disturbance, distance of bighorn sheep to road, distance of bighorn sheep to escape terrain) on the behavioral response of bighorn sheep. We ranked the relative weight of each significant independent variable on behavioral response using Akaike Information Criterion (AIC; Akaike 1973).

We compared the effects of independent variables on bighorn sheep response between and within study areas using Fisher Exact tests for 4 × 2, (Mielke and Berry 1992), 3 × 2, and 2 × 2 tables (Berry and Mielke 1985, 1987). Larger tables (4 × 3, 4 × 4) were analyzed using nonasymptotic chi-square analysis (Berry and Mielke 1988).

The effects of independent variables on the distance fled by sheep, the duration of sheep response to disturbances, and the distance at which sheep first responded were analyzed with nonparametric Kruskal-Wallis 1-way analysis of variance (ANOVA; Siegel 1956). Except for Fisher Exact and nonasymptotic chi-square tests, we used Systat 7 (SPSS 1997) for all analyses. We report only the probability values for Fisher Exact tests and nonasymptotic chi-square tests. Probability values ≤0.10 were considered significant.

We mapped bighorn sheep habitat to determine whether it was more or less available than expected along the road corridor and whether these habitat availability differences might influence the number of animals seen along the road corridor. Habitat was mapped using the geographic information system (GIS) habitat evaluation procedure developed by Smith et al. (1991) for Rocky Mountain bighorn sheep (*O. c. canadensis*), with modifications made by Johnson and Swift (2000). Criteria for the GIS model of suitable habitat were based on habitat use by radiocollared animals (Smith et al. 1991). Subsequent tests indicated >90% of radiolocations of animals were found in the mapped predicted habitat (Smith and Flinders 1991, Zeigenfuss et al. 2000).

To assess the impact of human disturbances of habitat used by bighorn sheep, we first determined the entire amount of modeled habitat, roads, and trails in the entire high- and low-use study areas using GIS procedures. Roads and trails through landscapes not used by sheep on the mesa top were removed from the analysis. We defined the road corridor for bighorn sheep as

Table 1. Summary of the influence of significant environmental factors (independent variables) on bighorn sheep response (no response, alert, walk away, run away) to hikers, vehicles, and mountain bikers using logistic regression analysis (n = 805). Increasing Akaike Information Criterion (AIC) values suggest decreasing degrees of influence.

Parameter	P	–21n(L)	Parameters	AIC	McFadden's Rho
Type of human activity	<0.0001	1761.65	3	1767.65	0.1178
Distance to road	<0.0001	1821.55	1	1823.55	0.0180
Relative position of disturbance	<0.0001	1875.55	3	1881.55	0.0164
Group composition	0.0008	1940.20	3	1946.20	0.0117
Group behavior	<0.0001	1946.66	4	1954.66	0.0244
Study area	<0.0001	1959.47	2	1965.47	0.0187
Season	<0.0001	1959.55	3	1965.55	0.0187
Distance to escape terrain	<0.0001	1966.98	1	1968.98	0.0128

the average distance of desert bighorn sheep to the road within each study area (353 m in the low-use area; 489 m in the high-use area), and we then mapped the modeled habitat within this corridor.

Forty-two desert bighorn sheep were captured with net gun from helicopters in the study areas in 1992 and 1993 and were monitored from the ground and by aircraft at regular intervals (Singer et al. 2000). The radiolocations of these animals from 1992 to 1995 were used to determine their distance from the roads. Due to the inherent errors in triangulating in the steep canyon country, only ground visual locations were used in the analysis.

RESULTS

We made 1,029 observations of bighorn sheep responses to human recreational activity during the spring, summer, and autumn of 1993 and 1994. Of these, 237 involved hikers (87 and 150 in the low-use and high-use areas, respectively), 370 involved vehicles (36 and 334), and 198 involved mountain bikers (9 and 189). The behavioral response of bighorn sheep did not differ (P> 0.10) with the number of stimuli (i.e., hikers [median = 1, range = 1–11], vehicles [median = 1, range = 1–7], or mountain bikers [median = 2, range = 1–13]), so these data were pooled. As groups sometimes consisted of mountain bikers with support vehicles, we made 73 observations of vehicles followed by mountain bikers and 108 of mountain bikers followed by vehicles. Because there were <4 of these convoys observed in the low-use area, we did not test for a study-area effect, but we did compare them with other types of disturbance. The remaining 43 observations were of varied types (e.g., aircraft, motorcycles), but none had a large enough sample size for detailed analysis.

Responses of Bighorn Sheep

The particular type of human activity was the most influential variable affecting the behavioral response of bighorn sheep to disturbance (i.e., had the lowest AIC value; Table 1). Interactions with hikers caused bighorn sheep to flee in 61% of interactions, far more than to vehicles or mountain bikers (P< 0.0001; Fig. 3). Sheep fleeing from hikers moved >100 m farther than sheep fleeing from vehicles or mountain bikers (t = 41.47, P< 0.0001; Fig. 4). Sheep also responded to hikers for 10 min longer than to vehicles or mountain bikers (t = 282.72, P< 0.0001; Fig. 5). These differences were likely due to the greater predictability of vehicle and mountain biker locations because when bighorn sheep did respond to human activity, they noticed vehicles and mountain bikers, on average, from twice the distance they noticed hikers (t= 65.04, P< 0.0001; Fig. 6).

Greater sensitivity of bighorn sheep to hikers in the high-use area over the low-use area was suggested by the more frequent responses of male

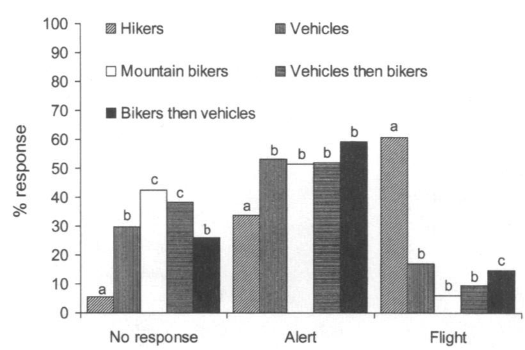

Fig. 3. Behavioral responses of desert bighorn sheep to human activity in Canyonlands National Park, Utah, 1993–1994. Different letters indicate significant difference.

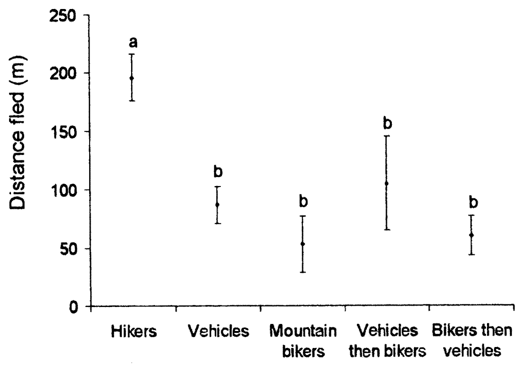

Fig. 4. Mean distances fled by desert bighorn sheep (if they fled) from human activity in Canyonlands National Park, Utah, 1993–1994. Capped lines are 1 standard error. Different letters indicate significant difference.

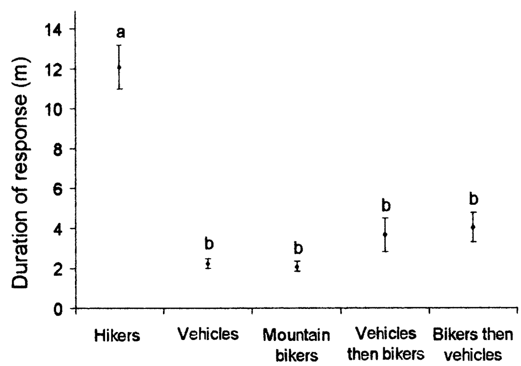

Fig. 5. Duration of responses by desert bighorn sheep (if they responded) to human activity in Canyonlands National Park, Utah 1993–1994. Capped lines are 1 standard error. Different letters indicate significant difference.

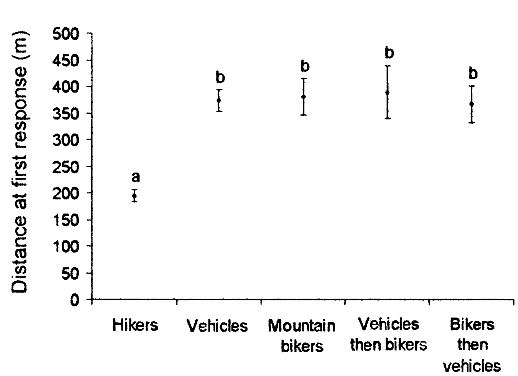

Fig. 6. Distance at which desert bighorn sheep first responded (if they responded) to human activity in Canyonlands National Park, Utah, 1993–1994. Capped lines are 1 standard error. Different letters indicate significant difference.

groups to hikers during autumn (100% response vs. 50%; $P = 0.069$) and the greater average distance fled by female groups from hikers during spring (468 ± 122 [SE] m, range = 24–1,706 vs. 140 ± 26 m, range = 24–427; $t = 204$, $P = 0.014$).

Habituation of bighorn sheep in the high-use area to human activity along the roads was suggested by the lower frequency of responses of female groups in the high-use area to vehicles in spring (67% response vs. 92%; $P = 0.062$), the shorter response time of sheep in the high-use area to vehicles in spring ($t = 560$, $P = 0.0001$), and the lower overall frequency of responses of bighorn sheep in the high-use area to mountain bikers (11% vs. 56%; $P = 0.037$) when compared to the low-use area. We were unable to measure any differences in bighorn sheep responses to vehicles in summer or autumn because sample sizes in the low-use area were too small for analysis. Habituation of sheep in the high-use area was also suggested by the greater distance of bighorn sheep in the high-use area to escape terrain (28 ± 3 m, range = 0–966) than those in the low-use area (17 ± 4 m, range = 0–300; $t = 2.14$, $P = 0.033$).

Influence of the Roads

Proximity to the road influenced bighorn sheep responses to human activity on the roads (Table 1), with sheep closer to a road more likely to flee than those farther away ($t = 221.2$, $P < 0.0001$). On average, sheep fled when 132 m (± 17, range = 0–1,143) from the road, alerted at 363 m (± 16, range 1–1,542), and did not respond at 821 m (± 38, range = 4–2,591). The duration of response by bighorn sheep to road based disturbances generally increased with the number of vehicles and mountain bikers involved ($P < 0.10$).

Avoidance of heavy road traffic by bighorn sheep was suggested by the greater average distance of all sheep from the road in the high-use area (490 ± 19 m, range = 0–2,590) than in the low-use area (354 ± 36 m, range = 6–762; $t = 3.32$, $P = 0.0014$). The GIS analysis indicated this corridor of less bighorn sheep activity in the high-use area included an additional 15.3% of the modeled habitat over the low-use area (Table 2).

We also found evidence of avoidance of the road corridors by 7 radiocollared desert bighorn sheep. Radiocollared sheep whose home ranges were bisected by road corridors were located more often outside than within the road corridor (65% vs. 35%, $P < 0.03$). Animals captured in the high-use area ($n = 12$) later used the high- and low-use areas equally; however, bighorn sheep

Table 2. Results of GIS analysis of modeled habitat within high- and low-use study areas, Canyonlands National Park, Utah.

Variables	Study area Low use	High use
Total habitat (TH)	532.0 km^2	197.1 km^2
Average distance of desert bighorn sheep to road	353 m	489 m
TH within average distance to road	107.3 km^2	70.0 km^2
Adjusted H (TH - zone of less use along road corridor)	424.7 km^2	127 km^2
Percent H within zone of less use along road corridor (adjusted H / TH)	20.2%	35.5%

that were captured in the low-use area (n = 11) were never found in the high-use area.

We observed individual heterogeneity in response to the heavily used road corridor. Some animals became habituated to the traffic along the roads. This habituation was most obvious for those radiocollared animals whose home ranges were entirely within the high-use area. Those 4 animals and their groups used the road corridor area more than expected; i.e., more than areas located away from the road corridor (64% vs. 36%, P = 0.089). Three of these animals were frequently observed directly adjacent to roads and were clearly habituated to the presence of vehicles and mountain bikers.

Other Factors Influencing Responses

We found that the behavioral response of sheep was also affected, in decreasing order of influence, by the relative position of human activity to sheep, composition of the sheep group, behavior of sheep prior to an interaction, season, and the distance of sheep to escape terrain (Table 1).

Human activity at the same elevation as bighorn sheep caused more severe responses than activity approaching from above or below: bighorns fled from a hiker at the same level in 87% of occurrences, from a vehicle in 25%, and from a bicycle in 12% (P < 0.001). Female groups responded to disturbances most often (79% of encounters), followed by male groups (69%) and mixed sex groups (47%; P = 0.0004). There was no difference in responses between female groups with lambs or those without (P = 0.33). Bighorns were more likely to flee when moving (43%) or standing (48%) at the time of the interaction than if they were feeding or watering (31%) or bedded (14%; P < 0.0001). Sheep also fled farther when moving or standing than when feeding/watering or bedded (t = 9.740, P = 0.020).

Female groups responded to 93% of interactions in summer, significantly more often than in autumn (73%) and spring (76%; P = 0.0006). Female groups fled farther in spring (249 ± 52 m, range = 15–1,707) than in summer (155 ± 32 m, range = 5–671) or autumn (104 ± 17 m, range = 2–396; t = 11.03, P = 0.004). Male groups fled more frequently in spring and summer (~30% of interactions) than in autumn (15%; P < 0.0001). However, when they fled, male groups fled similar distances in all seasons (t = 4.08, P = 0.13). Mixed groups were generally observed only in autumn, and no comparison among seasons was made. Proximity of bighorn sheep to escape terrain reduced the severity of responses to disturbance (P < 0.0001).

DISCUSSION

Our finding that hikers cause the greatest disturbance of bighorn sheep concurs with that of MacArthur et al. (1979). We speculate that the higher sensitivity of sheep to hikers was due to the greater unpredictability of the locations of hikers because, unlike road traffic, nearly all hiker disturbances of sheep were off-trail and in variable locations. Also, hikers often surprised desert bighorn sheep at closer distances because they approached them. Vehicles and mountain bikers were restricted to the roads and were thus predictable to sheep. Bighorn sheep first noticed vehicles and mountain bikers at much greater distances than they first noticed hikers, which likely reduced the severity of their response to these activities.

Our results suggest that sheep in the high-use area were more sensitive to approaching hikers than in the low-use area. During spring, females in the high-use area fled from hikers >3× farther than females in the low-use area. The increased sensitivity of bighorn sheep to hikers, especially during the lambing season and rut, is of concern because of the potentially negative effects on reproductive fitness at these times. During spring, hikers could have a detrimental impact on lactating or lambing females (Moen 1981). The increased expenditure of energy resulting from disturbances could force females and lambs into habitat with less escape cover, making lambs more vulnerable to predation. Excessive disturbances of males during rut could disrupt their opportunity to find mates. Summer can also be a critical period for bighorn because nutrient content available to local vegetation is particularly low relative to the requirements for lactating females and lambs (Hull 1984).

We concluded some animals in the high-use area had become habituated to the road traffic. Some radiocollared animals captured near the road in the high-use area used the road corridor frequently with their groups and seldom responded to human activity. This conclusion was also supported by a lower frequency of responses by female groups in spring and shorter response times of all groups to vehicles in spring. Additionally, visible responses to mountain bikers were less frequent in the high-use area. The greater distance of bighorn sheep from escape terrain in the high-use area provided further evidence of habituation. Other studies have also found evidence of habituation by free-ranging bighorn sheep to human activity (Geist 1975, Horejsi 1976, DeForge 1981, Stanger et al. 1986). Bighorns may even habituate to hikers, but only if hikers remain in predictable locations on well used trails (Hicks and Elder 1979, Hamilton et al. 1982, Holl and Bleich 1987), and not in unpredictable off-trail situations as was the case for hikers in our study area.

On the other hand, most bighorn sheep generally avoided the more heavily used road corridor. The greater average distance of sheep from the road in the high-use area, no dispersal of sheep from the low- to high-use area, and avoidance of road corridors by most radiocollared animals support this conclusion. These findings of road avoidance by sheep concur with Wilson et al. (1980), Krausman et al. (1989), and Ebert and Douglas (1993), who reported that roads exert a zone of influence larger than the road itself. In Canyonlands NP, the avoidance of roads may be biologically significant because the area receiving less use in the high-use area represented an additional 15.34% of habitat available to bighorn sheep over the low-use area.

MANAGEMENT IMPLICATIONS

Hikers appear to be causing the most frequent responses and most flights by bighorn sheep, especially when approaching sheep to view or photograph them. We recommend that hikers be confined to maintained trails where their movement will be more predictable to sheep.

Additionally, known lambing habitat should be closed to all hiking during the reproductive season. Public education could help reduce impacts of recreation on bighorn sheep by explaining the impact hikers can have on sheep and cautioning them not to directly approach sheep.

Contrary to our original expectations and the concerns of park managers, the increase in number of mountain bikers visiting the park does not appear to be a serious threat to desert bighorn sheep, probably because mountain bikers are restricted to predictable situations such as the currently designated road corridors. However, these results should not be extrapolated to other public lands where mountain bikers are not confined to designated trails and may surprise sheep in novel situations.

Though some individual bighorn sheep in the Canyonlands appear to be habituated to road activity, individuals in the same area and other animals that were subjected to a lower rate of disturbances, and apparently all animals that are subject to human disturbances in novel locations (i.e., to off-trail hikers), were more disturbed by humans. Our observations of individual heterogeneity in habituation versus avoidance behaviors by different bighorn sheep verifies the need to couple field studies with experimental studies conducted under artificial conditions. Although Krausman et al. (1998) and Workman et al. (1992) documented habituation of bighorn sheep in experiments in penned situations, our study of free-ranging desert bighorn sheep verified that only some, but not all, radiocollared animals habituated to road traffic.

We documented avoidance of the road corridor by other desert bighorn sheep at levels that were probably biologically important (zones of less use along road = 20–36% of all suitable habitat in the study area), and we recommend that park managers manage levels of backcountry activity at low levels. We recommend staggering removals of animals for translocation purposes across the landscape and only removing animals from the road corridor that can be replaced with recruitment, since animals from other areas apparently do not readily disperse to the high-use road corridor and dispersal may not assist in their replacement. We also recommend further study to determine the long-term impacts of this reduced use of suitable habitat by desert bighorn sheep.

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